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MID-TERTIARY DEFORMATION OF WESTERN NORTH AMERICA

by

HYRUM SCHNEIDER

A Thesis Submitted for the Degree of

MASTER OF ARTS

UNIVERSITY OF WISCONSIN

1911

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I N T R O D U C T I O N.

It is quite generally conceded that the Tertiary period in North America was ushered in by a marked deformation most conspicuous in the Rocky Mountain region, and was ushered out by another deformation which probably affected to some extent most of North America, but in its more marked features was confined to the Pacific Coast. Somewhere near the middle of the Tertiary there was a deformation somewhat analogous to the opening and closing disturbances.

The problems of this thesis are an investigation of the middle Tertiary deformation:- (a) to locate it as nearly as possible in time; (b) to investigate its nature and extent; (c) to determine some of its effects; (d) to study its relation to mid-Tertiary deformations in other parts of the world; (e) if possible to find out something about its cause.

The work is based largely on facts and opinions gleaned from the following publications:-

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Ralph Arnold: Environment of the Tertiary Faunas of the Pacific Coast of the United States, Jour. of Geol., Vol. 17, 1909, p. 509.

Ralph Arnold: Coal in the Mount Diablo Range, Monterey County, California. U. S. Geol. Survey, Bull. 285, 1905, pp. 223-225.

Ralph Arnold: The Los Angeles Oil District, Southern California. U. S. Geol. Survey, Bull. 309, 1907, pp. 139-199.

Ralph Arnold: Geological Reconnaissance of the Coast of the Olympic peninsula, Washington. Bull. Geol. Soc. Am., Vol. 17, 1906, pp. 451-468.

Ralph Arnold: personal letter, March 27, 1911.

S. H. Ball: Geological Reconnaissance across southwestern Nevada and eastern California. U. S. Geol. Survey, Bull. 308, 1907.

Eliot Blackwelder: Cenozoic History of the Laramie Region, Wyoming. Jour. of Geol., Vol. 17, No. 5, 1909, p. 429.

Branner, Newsom, Arnold: Santa Cruz, California. U. S. Geol. Survey, folio #163, 1909.

A. H. Brooks: Coal Resources of Alaska. U. S. Geol. Survey, 22nd Ann. Rep., part 3, 1901.

A. H. Brooks: The Geography and Geology of Alaska. U. S. Geol. Survey, Prof. Paper 45, 1906.

T. C. Chamberlin and R. D. Salisbury: Earth History, Vol. III, 1907.

W. H. Dall: Contributions to the Tertiary Paleontology of the Pacific Coast, U. S. Geol. Survey, Prof. Paper 59, 1908.

N. H. Darton: Paleozoic and Mesozoic of Central Wyoming. Bull. Geol. Soc. Am., Vol. 19, 1908, pp. 403-470.

N. H. Darton: Geology and Underground Waters of the Arkansas Valley in eastern Colorado. U. S. Geol. Survey, Prof. Paper 52, 1906.

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J. S. Diller: Coos Bay, Oregon. U. S. Geol. Survey, folio #73, 1901.

J. S. Diller: Redding, California. U. S. Geol. Survey, folio #138, 1906.

J. S. Diller: U. S. Geol. Survey, 14th Ann. Rep., part II, p. 421.

C. E. Dutton: Tertiary History of the Grand Canyon district. U. S. Geol. Survey, Mon. II, 1882.

W. H. Fairbanks: San Louis, California. U. S. Geol. Survey, folio #101, 1904.

Huntington and Goldthwait: The Hurricane Fault in the Toquerville district, Utah. Harvard Col. Mus. Comp. Zool., Bull. Vol. 42, 1904, pp. 199-259.

A. W. Lawson: San Francisco Peninsula. U. S. Geol. Survey, 15th Ann. Rep., 1895.

W. T. Lee: Geologic Reconnaissance of a part of Western Arizona. U. S. Geol. Survey, Bull. 352, 1908.

Leith and Harder: Iron Springs district, Utah. U. S. Geol. Survey, Bull. 338, 1908.

G. C. Martin: Geology and Mineral Resources of the Controller Bay Region, Alaska. U. S. Geol. Survey, Bull. 335, 1908, p. 42.

J. C. Merriam and W. J. Sinclair: Tertiary Faunas of the John Day Region. University of California, publications Bull. of Dept. of Geol., Vol. 5, No. 11, 1907, pp. 171-205.

Sidney Paige and Adolph Knopf: Geologic Reconnaissance in Matanuska and Talkeetna Basins, Alaska. U. S. Geol. Survey, Bull. 327, 1907.

L. M. Prindle: The Gold Placers of Fortymile Birch Creek, and Fairbanks regions, Alaska. U. S. Geol. Survey, Bull. 251, 1905.

L. M. Prindle and F. L. Hess: The Rampart Gold Placer region, Alaska. U. S. Geol. Survey, Bull. 280, 1906.

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F. L. Ransome: The Geology and Ore Deposits of Goldfield, Nevada. U. S. Geol. Survey, Prof. Paper 66, 1909.

F. C. Schrader: Geologic Section of the Rocky Mountains in northern Alaska. Bull. Geol. Soc. Am., Vol. 13, 1902, p. 233.

George Otis Smith: Contributions to Geology of Washington. U. S. Geol. Survey, Prof. Paper 19, 1903.

George Otis Smith and F. C. Calkins: Snoqualmie. U. S. Geol. Survey, folio #139, 1906.

James Perrin Smith: Salient Events in the Geologic History of California. Science, new ser., Vol. 30, 1909, pp. 346-350.

J. E. Spurr: Nevada south of the Fortieth Parallel and Adjacent Portions of California. U. S. Geol. Survey, Bull. 208, 1903.

Eduard Suess: The Face of the Earth, Vols. I-II.

W. H. Turner: U. S. Geol. Survey, 14th Ann. Rep., pt. II, p. 443.

Bailey Willis: Structure of the Front Range, Northern Rocky Mountains, Montana. Abstract: Science, new ser., Vol. 15, 1902, pp. 86-87.

Bailey Willis: Research in China, Vol. II, 1907, p. 97.

The above comprises so far as the writer has determined a fairly complete list of references, at present available, which have any direct bearing on the problem.

The writer wishes to express his thanks to Professor Eliot Blackwelder for suggestions and criticisms.

In North America the mid-Tertiary deformation affected either by folding, faulting or uplift the western part of

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the continent from the Pacific coast to the Great Plains region east of the Rocky Mountains; farther east its effect is not notable. Within the disturbed area the deformation was far from uniform. There were regions of close folding, regions of gentle folding, and regions of uplift without folding. Each of these will be discussed separately and in detail.

The mid-Tertiary disturbance of other continents will be discussed only in a very general way to indicate its extent and distribution.

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McKINLEY'S DESK OUTLINE MAPS. DOUBLE SIZE. No. 207. NORTH AMERICA.

Subject Miocene Deformation.

Date

Legend { Heavy blue; close folding
Light blue; gentle folding
Red; upheaval without folding

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W E S T E R N N O R T H A M E R I C A.

GENERAL CONCLUSIONS.

Near middle Miocene time there began in western North America a period of disturbance which affected profoundly the Pacific Coast region from southern California to Puget Sound and probably extended along the coast to northern Alaska. From southern California it probably extended south to Central America. Passing east from California, the western part of the Great Basin was markedly affected, the eastern part to a less degree, and the disturbance practically died out in the Great Plains east of the Rocky Mountains.

The Coast Ranges, part of the Cascade Range, the Olympic Mountains, and a part of Alaska were closely folded. In the Coast Ranges horizontal thrust faulting accompanied the folding. At least a part of Alaska, the Coos Bay region of Oregon, the John Day Basin of Oregon, and the western part of the Great Basin were moderately folded. In the western part of the Great Basin the folding was probably accompanied by normal faulting on a large scale. The Sierra Nevada mountains were uplifted bodily without folding. The eastern part of the Great Basin and the Rocky Mountain region

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were uplifted and locally faulted.

EVIDENCE.

I. AREAS OF CLOSE FOLDING.

The Coast Range Region.

Facts. Ralph Arnold[a] in a diagram of the structure at the Stone Canyon Coal mine in Monterey County, California, shows a marked structural unconformity between the upper and lower Miocene sandstone. The lower Miocene beds dip at an angle of about 65° and the upper Miocene sandstones dip at an angle of about 30°.

H. W. Fairbanks[b] in a structure section for the San Louis district shows the Santa Margarita almost horizontal on closely folded truncated Monterey. Both are Miocene. The axes of the folds roughly parallel the coast. The structure sheet also shows some faults which appear to be of the same age as the folding. The fault planes trend in the same direction as the axes of the folds, and in all cases are shown as nearly vertical, with the down throw

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[a] Ralph Arnold: Coal in the Mount Diablo Range, Monterey County, California. U. S. Geol. Survey, Bull. 285, p. 224.

[b] H. W. Fairbanks: San Louis, Cal. U. S. Geol. Survey, folio #101, 1904.

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on the ocean side.

A section in the Santa Cruz folio shows the same relations between the Monterey and Santa Margarita as is shown in the San Louis section. The section shows the Oligocene, as represented by the Bunta sandstone and the San Lorenzo, and the Miocene represented by the Vaqueros and Monterey folded up together as though they had been folded at the same time. From the appearance of the section and the relation of the Oligocene and Miocene there appears to have been no folding at the close of the Oligocene. The structure sheet also shows a number of faults which appear to belong to the post Monterey deformation. Their planes are shown nearly vertical and roughly parallel to the axes of the folds. In some places the down throw is on the ocean side and in others on the continent side. Along one fault plane the down throw is on the ocean side near the north end of the area and about 8 miles south, along the same fault plane, it is on the land side, showing pivotal faulting.

The authors believe the faults to be principally of the thrust type, with horizontal displacement. Some of the fault planes are thought to represent planes of weakness, which have been such since early Tertiary or even pre-Tertiary time. One of the chief of these is the San

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Andreas fault, along which the San Francisco earthquake took place in 1906. The displacement was horizontal, the maximum being 8½ feet. The northeast side of the fault moved southeast relative to the southwest side. As at San Louis the axes of the folds and the fault planes are roughly parallel to the coast.

Opinions and Inferences. Ralph Arnold[a] speaks of two systems of disturbances in the region about Los Angeles. The older consists primarily of folds usually associated with faults. This system dominates the Miocene strata and was probably developed during the late middle Miocene readjustment which had such a widespread effect throughout the Pacific Coast of the United States.

Lawson[b] speaks of a post Miocene disturbance (no doubt meaning post Monterey) which affected profoundly the Coast ranges generally. He cites as evidence the removal of the Monterey from the greater part of the San Francisco peninsula before the Pliocene depression.

James P. Smith[c] says the vast outpouring of the Colum-

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[a] Ralph Arnold: The Los Angeles Oil District, Southern California. U. S. Geol. Survey, Bull. 309, 1907, p. 155.

[b] A. W. Lawson: San Francisco Peninsula, 15th Annual Report, U. S. Geol. Survey, 1895, p. 463.

[c] James P. Smith: Salient Events in the Geologic History of California. Science, new ser., Vol. 30, 1909, p. 348.

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bia lava flow which covered an area of over 200,000 square miles, including the northeastern part of California, occurred about the middle Miocene and the Coast range disturbance was probably a local phase of the same revolution. Smith recognizes a middle Miocene disturbance and associates it with the vast lava flow which took place near the middle of the Miocene. Geologically speaking, the two occurred in the same period, but as will be shown by evidence introduced later, they are distinctly separate in time.

The Cascade Region and the Olympic Mountains.

Facts. Smith and Calkins[a] in a structure section in the Snoqualmie quadrangle, show the Guye formation (Miocene) strongly folded and eroded with the Keechelus andesite series (Miocene or Pliocene?) flat lying on the truncated edges of the Guye. In the southern part of the quadrangle the lower portion of the Keechelus is overlain by the Ellensburg.

Inferences. The Ellensburg, by means of its fossil plants, has been determined as later Miocene. Therefore the lower portion of the Keechelus is undoubtedly Miocene.

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[a] George Otis Smith and F. C. Calkins: Snoqualmie. U. S. Geol. Survey, folio #139, 1906.

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The Guye is earlier Miocene, the folding in the Snoqualmie region is post-Guye and pre-Keechelus, hence the disturbance must have taken place somewhere near the middle of the Miocene.

George Otis Smith[a] speaks of later Miocene mountain building movements in Washington. Ralph Arnold[b] refers to middle Miocene diastrophism, marked by folding, faulting and warping, which affected profoundly the Pacific Coast from Puget Sound to southern California. In his article[c] on Geological Reconnaissance in the Olympic peninsula, he says "A great uplift in the Olympic peninsula region appears to have taken place at or near the close of the Miocene epoch". The axes of the determinable folds in the Olympic Mountains and in the Snoqualmie area strike NW-SE. The general strike of the coast is nearly N-S but the Olympic range trends in about the direction of the axes of the folds.

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[a] George Otis Smith: Contributions to Geology of Washington. U. S. Geol. Survey, Prof. Paper 19, 1903, p. 22.

[b] Ralph Arnold: Environment of the Tertiary Faunas of the Pacific Coast of the United States, Jour. of Geol., Vol. 17, 1909, p. 509.

[c] Ralph Arnold: Geological Reconnaissance of the Coast of the Olympic Peninsula, Washington. Bull. Geol. Soc. Am., Vol. 17, 1906, p. 468.

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Controller Bay Region, Alaska.

G. C. Martin[a] has found pre-Quaternary rocks in the northeastern part of the Controller Bay region, closely folded and in places complexly overturned. The close folding is accompanied by a complicated system of overthrust faults.

The rocks are not definitely located in age, and the time of their deformation is uncertain, but is thought to be late Tertiary. If the folding took place during Tertiary time it was probably contemporaneous with the post-Monterey folding in California.

II. AREAS OF MODERATE AND GENTLE FOLDING.

Coos Bay region, Oregon.

Facts. J. S. Diller[b] in a structure section of the Coos Bay region shows the Empire formation flat lying on the moderately folded truncated edges of the Arago (Oligocene). If the age of the Empire were definitely determined the exact time of the Coos Bay deformation might be obtain-

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[a] G. C. Martin: Geology and Mineral Resources of the Controller Bay Region, Alaska. U. S. Geol. Survey, Bull. 335, 1908, p. 42.

[b] J. S. Diller: Coos Bay, Oregon. U. S. Geol. Survey, folio #73, 1901.

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ed. But the Empire has not yet been definitely correlated; it may be either upper or lower Miocene and the deformation may come anywhere between the Oligocene and later Miocene. The axes of the folds roughly parallel the coast.

Ralph Arnold[a] thinks there was but one period of folding (the post Monterey) which affected the Pacific Coast within Tertiary time.

Inferences. If there was but one period of folding on the Pacific coast within Tertiary time, as is indicated by the available evidence, then it is highly probable that the Arago formation in the Coos Bay region was folded at the time of the folding of the Monterey in California.

The John Day Basin, Oregon.

Facts. Merriam[b] has found the John Day formation lying between the upper Clarno (upper Eocene) and the Columbia lava. It is separated from the Columbia lava by an interval of gentle folding and sub-areal erosion. The Columbia lava is overlain by the Mascall which has been determined as later Miocene. The Mascall is the equivalent of the Ellensburg formation, and the Columbia lava

---

a/ Ralph Arnold: personal letter, March 27, 1911.

b/ J. C. Merriam and W. J. Sinclair: Tertiary Faunas of the John Day Region. University of California, Bulletin of the Dept. of Geol., Vol. 5, No. 11, 1907, p. 193.

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is a correlative of the Yakima basalt.

Inferences. The outburst of lava which put down the Columbia and the Yakima, followed closely upon the period of disturbance, but, as shown by the truncation of the folds, there was an erosion interval between the folding and the outpouring of the lava.

G. O. Smith[a] places the Yakima basalt in the middle Miocene. If Smith is right and the Columbia lava is the correlative of the Yakima, then the John Day beds were folded some time before the middle Miocene.

But inasmuch as available evidence points to but one period of folding near mid-Tertiary time it is highly probable that the Columbia lava is late middle Miocene and the gentle folding of the John Day took place at the same time as the close folding of the Guye formation in the Cascade Ranges and the Monterey in the Coast Ranges of California.

Alaska.

The most definite evidence regarding the mid-Tertiary deformation in Alaska is the fact that the Kenai formation

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[a] George Otis Smith: Contributions to Geology of Washington. U. S. Geol. Survey, Prof. Paper 19, 1903.

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as shown by Brooks[a], Mendenhall[b], Prindle[c], Paige and Knopf[d] is almost everywhere more or less folded and in some areas faulted. The Kenai has been determined as upper Eocene by Knowlton. Locally the folding is quite steep but generally it is rather gentle with dips as low as 4° and 5°.

The folded Kenai shows clearly a post-Kenai period of folding, but the upper limit is not very well determined. Paige and Knopf[d] in the Matanuska and Talkeetna Basins found a series of post Eocene lava flows nearly horizontal and supposedly unconformable on the Kenai and older rocks. They think that before the disturbance which folded the Kenai, planation was well advanced, the rivers broad, and filled with well rounded gravels. The disturbance initiated a new cycle of erosion which was interrupted by an extensive outburst of lava flows. While the time of disturbance in Alaska cannot be definitely established, it is certainly post Eocene. That, taken in connection with the evi-

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a/ A. H. Brooks: Coal Resources of Alaska. U. S. Geol. Survey, 22nd Ann. Rep., part 3, p. 537.

b/ W. C. Mendenhall, Geology of the central Copper River region, Alaska. U. S. Geol. Survey, Prof. Paper 41, 1906, p. 79.

c/ L. M. Prindle: The Gold Placers of Fortymile Birch Creek, and Fairbanks regions, Alaska. U. S. Geol. Survey, Bull. 251, 1905, p. 32.

d/ Paige & Knopf: Geologic Reconnaissance in Matanuska and Talkeetna Basins, Alaska. U. S. Geol. Survey, Bull. 327,1907.

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dence in California and Washington, makes it highly probable that the Alaskan disturbance took place at the same time as the disturbance farther south, viz., near the middle Miocene.

The Western Part of the Great Basin.

Facts. Ransome[a] in a structure section in the Goldfield district shows somewhat folded, truncated Siebert formation (lake beds) overlain by horizontal Malpais basalt.

Inferences. The Siebert or Pahute lake has been considered Miocene by King, Spurr and Ball; Ransome is doubtful as to just where it belongs. He cites various opinions and shows that the paleontologic evidence, based on diatoms which have a very wide geologic range, is inconclusive. King considered the beginning of the Lake period as Miocene. There is no evidence to show that he was wrong and no evidence to prove that he was right. Ransome places the Malpais basalt provisionally as Pliocene.

The Goldfield section when considered alone is inconclusive but when considered with the California evidence it seems highly probable that the disturbance which folded the Siebert beds at Goldfield took place near the middle of the Miocene.

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[a] F. L. Ransome: The Geology and ore deposits of Goldfield, Nevada. U. S. Geol. Survey, Prof. Paper 66, 1909.

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Spurr[a] in speaking of the Excelsior range says limestones supposedly early Tertiary and a series of sandstones and shales (the relative age of limestones, sandstones and shales not definitely known) are all folded together. The folding was followed by a cycle of erosion which preceded the formation of the Pliocene lake. He says at another place[b], "At Meadow Valley Canyon there was a general comparatively gentle folding, preceding the deposition of something like 2,000 feet of conglomerate and sandstone, presumably Pliocene lake deposits".

In speaking[c] of the region in general he says a period of sluggish streams and low relief reached its maximum in Miocene time. This period was followed by one of general disturbance consisting in part of differential movement, and the whole mass of the Sierras was uplifted 4,000 feet. This disturbance caused a change from slow sluggish streams and low relief to accelerated streams which cut deep valleys and left sharp ridges between.

Lee[d] considers the Miocene a time of mountain making

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a/ J. E. Spurr: Nevada south of the Fortieth Parallel and Adjacent Portions of California. U. S. Geol. Survey, Bull. 208, 1903, p. 113.

b/ Loc. cit., p. 148.

c/ Loc. cit., p. 220.

d/ W. T. Lee: Geologic Reconnaissance of a part of western Arizona. U. S. Geol. Survey, Bull. 352, 1908, p. 59.

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and great volcanic disturbance in the Great Basin and ranges west of it. Ball[a] speaks of a late Miocene deformation which destroyed the Pahute lake and by differential uplift blocked out the mountains as they now are, and uplifted the whole region.

The Tertiary formations of the western part of the Great Basin do not contain fossils and hence cannot be definitely correlated. Without a definite correlation of the formations the exact time of the disturbance cannot be determined. The opinions of Spurr, Ball and Lee must be based largely on inference drawn from physical evidence and the evidence of other areas. Standing alone the opinions would not be worth much but when backed by the definite evidence of Miocene folding on the Coast, with no evidence of more than one period of Tertiary folding in the region, it is probable that there was a Miocene deformation in the western part of the Great Basin contemporaneous with the middle Miocene period of folding on the Coast.

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[a] S. H. Ball: Geological Reconnaissance across southwestern Nevada and eastern California. U. S. Geol. Survey, Bull. 308, 1907.

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III. UPLIFT WITHOUT FOLDING.

The Sierra Nevada Mountains.

Facts. J. S. Diller[a] in a structure section in the Redding quadrangle, which is near the north end of the Sacramento valley, shows the Chico formation (Cretaceous) horizontal, proving that in that particular region there has been no folding since Cretaceous time.

Inferences. Though no folding took place there appears to have been about the time of the post-Monterey deformation, a bodily uplift. The upheaval caused the complete removal of the Ione formation (Miocene) in the Redding quadrangle before the deposition of the Tuscan Tuffs which are thought to be Pliocene. Spurr[b] believes that sometime in the Miocene the Sierra Nevada mountains were uplifted 4,000 feet.

It will be noted that there was folding on both sides of the Sierras, while the Chico formation in the Sierras remains horizontal. This interesting situation may perhaps be explained on the basis of competent and incompetent

---

a/ J. S. Diller: Redding, California. U. S. Geol. Survey, folio #138, 1906.

b/ J. E. Spurr: Nevada south of the Fortieth Parallel and Adjacent Portions of California. U. S. Geol. Survey, Bull. 208, 1903, p. 220.

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structures. At the close of the Jurassic period the rocks in the Sierras were folded, deformed and more or less metamorphosed so that they represented a fairly competent structure. At the time of the middle Miocene disturbance they naturally were much more competent than the later horizontal sediments east and west of them, and hence transmitted the tangential compressional thrusts without being further folded themselves.

See diagrams on plate I, page 20a.

The Colorado Plateau region.

Facts. A structure section in the Globe[a] quadrangle shows the Gila conglomerate listed as Quaternary conformable on the Whitetail formation listed as Eocene(?). The section indicates no folding since the Whitetail was put down.

Inferences. Dutton[b] is of the opinion that near the close of the Miocene the Grand Canyon region was uplifted from 2,000 to 3,000 feet. The uplift was accompanied by faulting. This uplift is assigned as the cause which initiated the cutting which has produced the present canyon.

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[a] Globe, Arizona. U. S. Geol. Survey, folio #111, 1902.

[b] C. E. Dutton: Tertiary History of the Grand Canyon district. U. S. Geol. Survey, Mon. II, 1882, p. 226.

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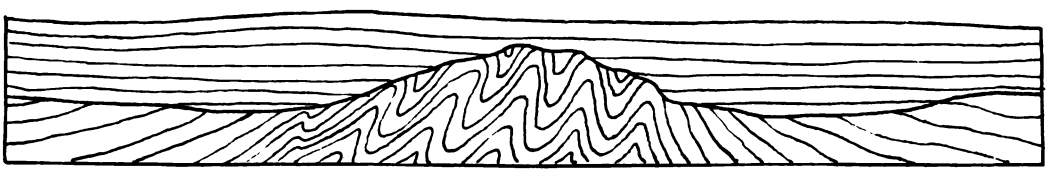
PLATE I.



Diagrammatic section across Sierra Nevada Mountains before middle Miocene folding.

Same section after middle Miocene folding.

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Davis[a] believes the uplift, which began the cutting of the present canyon, to be distinctly later than the uplift which accompanied the chief movement of the Hurricane fault.

Huntington and Goldthwait[b] speak of a period of folding, faulting and flexing which was probably completed some time in the Miocene. The folding, they say, is local and took place only along the line of the Hurricane fault near Toquerville. There the folding is of the Appalachian type, - comprest folds, with small overthrust faults. Most of the flexing of the Plateau region is of the simple monoclinal type.

Leith and Harder[c] speak of an intrusive with extensive flows, accompanied by deformation, which affected the region about Iron Springs in southern Utah in the late Miocene.

Rocky Mountain Region.

A structure section[d] in the Little Belt quadrangle

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a/ W. M. Davis: An Excursion to the Plateau Province of Utah and Arizona. Harvard Col. Mus. Comp. Zool., Bull. Vol. 42, 1903-5, p. 1-50.

b/ Huntington & Goldthwait: The Hurricane Fault in the Toquerville district, Utah. Harvard Col. Mus. Comp. Zool., Bull. Vol. 42, 1903-5, pp. 218-223.

c/ Leith and Harder: Iron Springs District, Utah. U. S. Geol. Survey, Bull. 338, 1908.

d/ Little Belt Mountains, Montana. U. S. Geol. Survey, folio #56.

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shows the Livingston formation (Cretaceous) folded and eroded and the Smith River lake beds (Neocene) flat on the eroded edges of the Livingston. There has been no folding in the area since the Smith River lake beds were put down.

Blackwelder[a] has found no notable deformation of Tertiary time in the Laramie region.

Darton[b] finds that in central Wyoming the deposition of the Arikaree beds (Miocene) was followed by an uplift and gradual erosion.

Bailey Willis[c] thinks that normal faulting probably of Miocene time resulted in a relative uplift of the mass of the Front Range of the Rockies and a down throw of the mass of the Flat head valley.

Darton[d] says that the deposition of the Arikaree formation (Miocene) in the Arkansas valley, Colorado, was followed by an uplift.

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a/ Eliot Blackwelder: Cenozoic History of the Laramie Region, Wyoming. Jour. of Geol., Vol. 17, No. 5, 1909, pp. 429-444.

b/ N. H. Darton: Paleozoic and Mesozoic of Central Wyoming. Bull. Geol. Soc. Am., Vol. 19, 1908, p. 469.

c/ Bailey Willis: Structure of the Front Range, Northern Rocky Mountains, Montana. Abstract: Science, new ser., vol. 15, 1902, p. 87.

d/ N. H. Darton: Geology and Underground Waters of the Arkansas Valley in eastern Colorado. U. S. Geol. Survey, Prof. Paper 52, 1906.

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The evidence bearing on a mid-Tertiary deformation in the eastern part of the Great Basin and the Rocky Mountain region is not the best, but such as it is, it points to the Miocene as a time of uplift. It is highly probable, therefore, that the great middle Miocene deformation of the Pacific Coast made itself felt in the eastern part of the Great Basin and in the Rocky Mountain region by simple uplift and faulting.

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SUMMARY AND CONCLUSIONS FOR WESTERN NORTH AMERICA.

TIME AND EXTENT OF THE DEFORMATION.

As shown by structure sections there was at about the middle Miocene a marked disturbance which affected profoundly the Pacific Coast from southern California to Puget Sound. As indicated by the folded Kenai (upper Eocene) overlain by later horizontal lavas it is supposed that the same disturbance affected Alaska. Evidence for British Columbia is lacking but it is probable that the disturbance was continuous along the coast between Alaska and the United States. Though evidence for Mexico is lacking it is probable that the disturbance extended south from California to Central America. At Limon[a] in Central America and also in Cuba and Jamaica, horizontal Pliocene is found on folded earlier Tertiary sediments. In the Great Basin definite evidence is lacking, but the concensus of opinion of geologists who have worked in the region is that there was in the Great Basin a disturbance by folding some time in the Miocene. This in connection with the folded Siebert beds at Goldfield strongly indicates

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[a] Eduard Suess: The Face of the Earth, Vol. IV, p. 456.

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that the middle Miocene disturbance of the Pacific Coast extended east into the Great Basin. And the uplift at the close of the Arikaree in Central Wyoming and in the Arkansas valley in Colorado make it probable that the same disturbance made itself felt in the Great Plains region east of the Rocky Mountains, altho not by folding.

NATURE OF THE DEFORMATION.

In the Coast Ranges there was close folding with differential movement accompanied by horizontal thrust faults. There was close folding in the Cascade Ranges and in the Olympic Mountains. West of the Cascades in the Coos Bay region, Oregon, there was moderate folding. East of the Cascades in the John Day Basin, Oregon, there was gentle folding. There was moderate folding in Alaska and in the western part of the Great Basin. In the Great Basin the folding was accompanied by normal faulting. The Sierra Nevada Mountains were probably uplifted bodily. The eastern part of the Great Basin and the Colorado plateau were uplifted and faulted. East of the Rocky Mountains in central Wyoming and in the Arkansas valley in Colorado there was a gentle uplift.

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EFFECTS OF THE DEFORMATION.

In the Pacific Coast region the disturbance was most profound with consequently more diverse pronounced effects. As shown by the folded truncated marine Monterey and Guye formations, submerged areas, where the Coast and Cascade ranges now are, were elevated thousands of feet. Arnold[a] thinks that parts of the areas, now known as the Sacramento and Willamette valleys, subsided and were submerged. In general mountain ranges were formed and deep basins produced, there was a marked increase in relief and a new active cycle of erosion was begun.

In the Great Basin the effects were of a similar nature as on the coast but they were not so diverse. The changes produced on the surface were not so marked, though in some parts of the Great Basin a period of active erosion has continued to the present time.

In the Rocky Mountain region the effects were less conspicuous than in the Great Basin. The gentle uplift simply accelerated erosion.

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[a] Ralph Arnold: Environment of the Tertiary Faunas of the Pacific Coast of the United States. Jour. of Geol., Vol. 17, 1909, p. 325.

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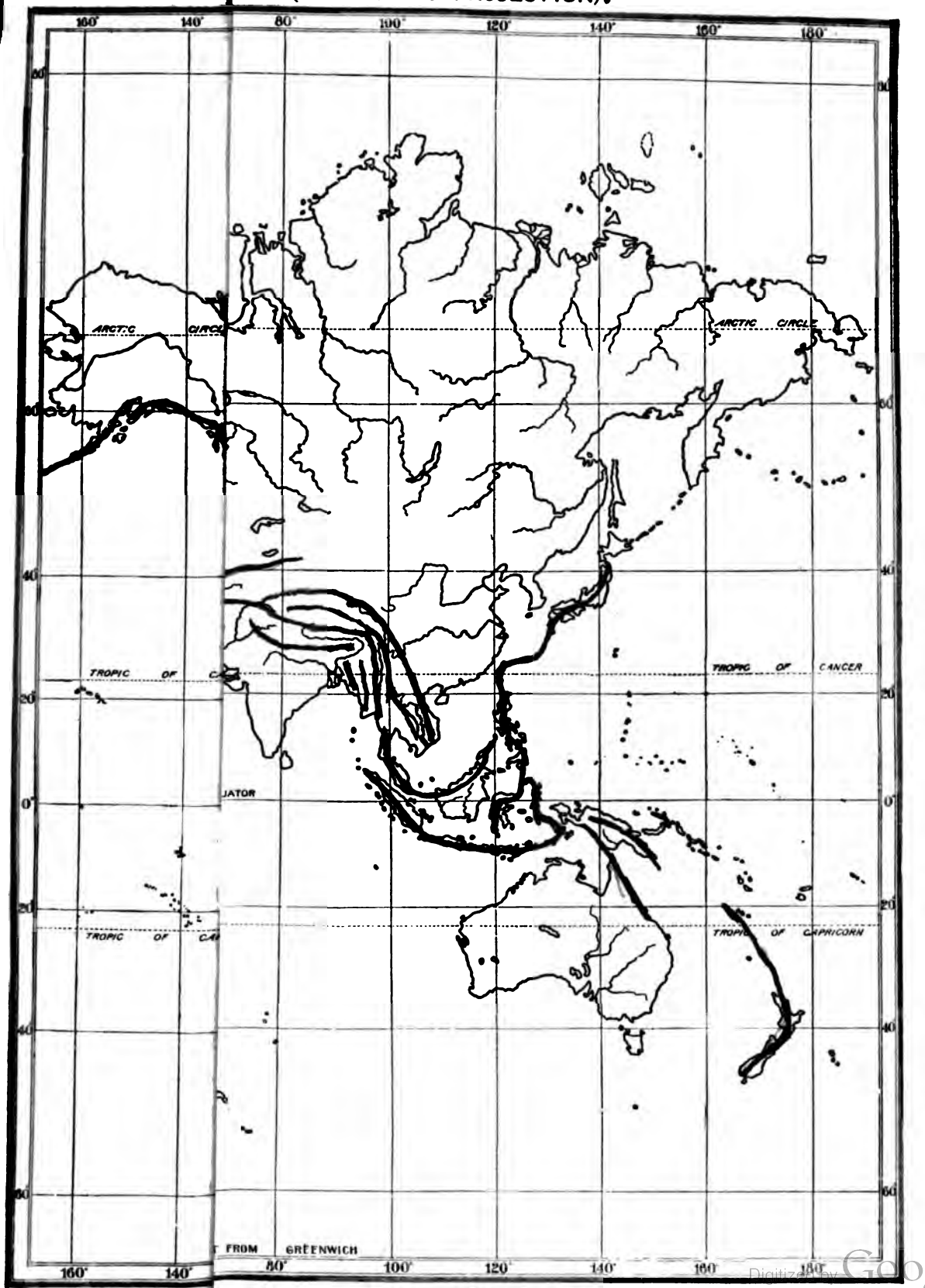
LD (MERCATOR'S PROJECTION).



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MID-TERTIARY DEFORMATION ON OTHER CONTINENTS.

While the main problem of this thesis is the investigation of the mid-Tertiary deformation in western North America, the disturbance was by no means limited to North America but as will be briefly shown, it affected some part or other of nearly every large land mass on the globe.

Following the disturbance from California south it is shown definitely in Guatemala,[a] Central America. The early Tertiary sediments are folded while the later Tertiary are not. Farther south at about latitude 10 N. folded Tertiary beds are exposed. At Limon on the east coast of Costa Rica Pliocene beds are horizontal.[b] F. B. Taylor extends the disturbance on into South America the full length of the western coast. The writer has been unable to find evidence to verify Taylor's conclusions. By consulting the "International Catalogue of Scientific Literature", volumes 1-7, also Suess, volumes I-IV, several references to South America were found, but not one mentioned

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[a] Eduard Suess: The Face of the Earth, Vol. IV, p. 451.

[b] F. B. Taylor: Bull. Geol. Soc. Am., vol. 21, No. 2, June, 1910.

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folded Tertiary. However, from the nature of the disturbance and the way it seems to follow the coast farther north it is probable that Taylor is right and that most of the western coast of South America was affected by the mid-Tertiary disturbance.

Passing from South America across the Pacific Ocean to the Orient we find in the Moluccas a little northwest of Australia folded middle Tertiary beds.[a] Passing on in a northwesterly direction to Borneo we find in the Bangkaloan mountains steeply folded Miocene limestones.[b] Continuing the journey in a northwest direction to northern India we find in the Himalaya mountains evidence of mid-Tertiary folding.[c]

Going west to the southern coast of Persia middle Tertiary strata are found either folded or over-folded while later marine deposits are horizontal.[d] These folded Tertiary beds are said to continue in the outer mountain area.

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a/ Eduard Suess: The Face of the Earth, Vol. III, p. 267.

b/ Idem, p. 255.

c/ Bailey Willis: Research in China, Vol. II, p. 97.

d/ Eduard Suess: The Face of the Earth, Vol. I, p. 506.

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from southern Persia in a northwesterly direction as far north as the Mediterranean sea. Going west into northern Africa, according to recent studies by French geologists, folded Miocene beds are found in the Atlas mountains.

Passing north across the Mediterranean to the Alps we again find definite evidence of a mid-Tertiary disturbance. The lower Miocene beds on the Alpine side of the Vienna Basin are folded. The upper Miocene at the same place are horizontal.[a]

Going east to Crimea, the peninsula in the Black Sea, there are two folded ranges said to be of Tertiary age. Continuing east to the Caucasus mountains Miocene strata are found as high as 2000 meters.[b]

Continuing east to the mountains of Amu Darya, folded Eocene is found.

While several of the cases of Tertiary folding cited give no evidence to fix their upper limit as Tertiary, enough definite cases are given to show that the mid-Tertiary disturbance was widespread. Naturally the query arises what is the cause of such a widespread deformation.

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a/ T. C. Chamberlin and R. D. Salisbury: Earth History, Vol. III, p. 280.

b/ Idem.

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CAUSE OF CRUSTAL DEFORMATION.

General Statement.

The cause of crustal deformation is a problem to which several able men have given considerable attention and energy, but because of lack of knowledge concerning earth dynamics it is still unsolved.

The writer does not attempt to solve the problem but there are a few facts which when considered jointly may throw some light on the question.

Review of post-Algonkian Deformation.

First let us review briefly the history of crustal deformation since pre-Cambrian time. The first, known in North America as the "Taconic disturbance", came about the close of the Ordovician, and so far as North America is concerned, it was in its more marked effects confined to an area of heavy Cambrian and Ordovician sediments along the Atlantic coast of the United States and extending north into Canada. There was contemporaneous with this disturbance a marked deformation in Europe.

The second disturbance in North America came about the middle Devonian, and may be called the "Acadian" because its notable effects have been observed best in the

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Acadian region. There was at the same time a strong deformation in northwest Europe.

The third great disturbance in North America is known as the Appalachian and is said to have come at the close of the Permian. It was confined so far as shown to a long narrow strip of thick sediments extending in a north-south direction from Alabama to New England. Bordering this area of disturbance on the east is the old Piedmont crystalline land area. In the process of folding there were many overthrusts the movement being from the ocean side toward the continent. The axes of the folds roughly parallel the coast. The European disturbance, corresponding to the Appalachian in America, appears to have come at the close of the Pennsylvanian.

The next or fourth great disturbance in North America, instead of coming in the east as the earlier disturbances did, came in the west where the Sierra Nevada Mountains now are. The area most affected was a trough with its long axis north-south in which had accumulated a great thickness of sediments. This disturbance came at the close of the Jurassic and altho in Europe its effects have been largely concealed, except around the Black Sea, it is marked all through Asia.

The fifth great disturbance took place at the close of

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the Cretaceous, and instead of happening near the coast as the earlier disturbance did, it came far inland in what is now the Rocky Mountain region. It probably extended north-south the full length of the Americas. The disturbance followed between two areas of thick deposits and was not the area of deepest sedimentation as is usually stated in textbooks.

The sixth great disturbance is the one with which this thesis is most concerned. It came as has been shown about the middle Miocene, and in North America, so far as close folding is concerned, was confined principally to the Pacific Coast. The folding is close, with horizontal longitudinal thrusts, indicating a differential movement between the continent and the ocean basin. In general it is as widespread throughout the world as any preceding period of deformation.

Conclusions. The review of the North American disturbances shows:

(1) Crustal deformation is periodic. A period of disturbance is followed by a period of quiescence.

(2) Deformations are not repeated in exactly the same area. Each new period of disturbance affects a new region.

(3) Deformation varies in intensity areally. Usually the sharpest folding is near coasts. Notable exceptions

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are the Rocky Mountains and the Alps.

(4) The folding occurred in regions of thick sedimentation. It appears that in North America these areas of thick sedimentation were basins with their long axes roughly parallel to the nearer coast, hence the axes of the folded areas when considered as a whole are roughly parallel to the coast.

(5) The overthrusts leaning toward the continent in the Appalachian region indicate compressional forces acting between the continent and the Atlantic Ocean basin. The active forces probably originated in the ocean basin. The horizontal thrusts of the middle Miocene deformation on the Pacific Coast indicate differential tangential compression between the continent and the Pacific Ocean basin.

The United States Coast and Geodetic Survey, by very careful work, has shown that on an average the highland areas have a lower density than the lowland areas, and that the continents have a lower density than the ocean basins.

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General Conclusions.

As geologic time goes on, the equilibrium of the earth is disturbed. T. C. Chamberlin and Bailey Willis have suggested erosion and redistribution of the sediments, coupled with a difference in density between the material underlying ocean basins and that making up the continents, as a cause of the disturbance of equilibrium. Whatever the cause, stresses seem to accumulate for long periods without effect until the elastic limit is reached, and a movement takes place. Naturally the strain expresses itself in areas of weakness. Regions of long sedimentation are weaker than older indurated rocks, hence the strain and readjustment for the re-establishment of equilibrium are most likely to manifest themselves in such areas.

Under ordinary conditions sedimentation takes place in belts along the borders of the continents, hence with conditions favorable for a thick deposit of sediments areas of weakness are produced with their long axes roughly parallel to the coast, therefore the areas of folding are usually near the borders of the continents and have the axes of the folds roughly parallel to the coasts. If the lines of weakness were inland or transverse to the coast the folding would probably be expressed along the

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lines of weakness regardless of their position on the continent or their direction.

About middle Miocene time, the accumulated stresses appear to have exceeded the elastic limit over a very wide area. The resulting strain and its effects is shown by folding in nearly all of the large land areas on the globe.

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